DOCUMENT RESUME

ED 253 416 SE 045 381

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TITLE Problem Solving in the Elementary School Mathematics Curriculum.
PUB DATE Nov 84
NOTE 46p.; Exit Project, Indiana University at South Bend.
PUB TYPE Information Analyses (070) -- Reference Materials - Bibliographies (131)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Annotated Bibliographies; Educational Change; Educational Research; Elementary Education; *Elementary School Mathematics; Literature Reviews; *Mathematics Instruction; *Problem Solving; Research Utilization
IDENTIFIERS *Mathematics Education Research

ABSTRACT

The purpose of this study was to examine the literature to find out if the recommendation by the National Council of Teachers of Mathematics (NCTM) that mathematics education should focus on problem-solving in the 1980s was being implemented or had caused any changes in the approach to teaching mathematics in the school curriculum. The study also sought to determine what materials are available for teachers who want to incorporate problem-solving instruction into the classroom mathematics program. The first part of the study presented annotated references on definitions of what mathematical problem-solving is and why it should be the focus of school mathematics programs. The middle section included annotated references on test results and research findings, in an attempt to determine if changes in programs have resulted from the NCTM recommendation and whether research has provided any clues about how to most effectively develop problem-solvers. Finally, proposals for future implementation of problem-solving-centered mathematics programs were formulated, based on information gained from research studies. A summary and conclusions are also presented. (MNS)

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PROBLEM SOLVING IN THE ELEMENTARY SCHOOL MATHEMATICS CURRICULUM

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Submitted in partial fulfillment of the requirements
for the course E591--Exit Project
Indiana University at South Bend
November, 1984

SE 045 381

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INTRODUCTION

In 1980, the National Council of Teachers of Mathematics published An Agenda for Action, Recommendations for School Mathematics for the 1980s. In that Agenda the NCTM urged that problem solving, applying mathematics to real situations, become the main focus of school mathematics programs in the 1980s.

Interest in problem solving abilities and how these abilities develop began with Piaget, who observed the conditions affecting the development of problem solving ability. He concluded that young children need to use concrete materials to solve problems while older children can reason and work verbal problems. Brownell (1942), building on Piaget's ideas, concluded that children are capable of solving problems when the problems are presented at the child's level of development and that practice in solving problems increased the child's growth in understanding. George Polya (1945), in his book How to Solve It, presented a four-step plan or strategy for attacking a problem: understand the problem, devise a plan, carry out the plan, look back.

It is apparent therefore that interest in mathematical problem solving is not something new. Why, then, did the NCTM call for an emphasis on this skill as the decade of the 1980s began? The NCTM conducted an extensive survey to determine the opinion of varied groups, including college, high school and grade school educators, administrators, and parents involved in PTA, about priorities for mathematics education.

Stress on problem solving skills was considered by all groups to be the most crucial and pressing need for math programs in the coming decade.

In this evolving technological era, in which rapid change and advances makes it hard, if not impossible, for teachers and schools to teach children all the information and skills they will need in the world of the future, the ability to think, to meet a challenge, to face a new situation and work from the known to the unknown will be increasingly important. With calculators and computers to do the computing, understanding of concepts, knowing what to tell the computer to do and recognizing if the information received is what is needed, is more important than proficiency in the computational skills.

However, current mathematics education is not teaching children to become problem solvers. The "back to basics" movement stresses drill and mastery of basic facts. Evaluations of test results indicate that schools are succeeding in training children to do simple arithmetic and one-step problems but are failing to teach applications, understanding, and estimating skills. (Lindquist, 1983; Bidwell, 1983, Carpenter, 1984) Research indicates the factors which contribute to success in problem solving as well as the factors which increase the difficulty of a problem. (Suydam, 1982; Silver, 1984) Children can learn strategies and methods to improve their problem solving skills when a systematic program of instruction is used. (Lester, 1982; Wheatley, 1983; Charles, 1984) Teachers develop self-confidence as well as their own problem solving abilities

when in-service programs provide practice in problem solving in an organized and systematic program. (Meiring, 1980; Gibney, 1983)

In order to implement the recommendations of the NCTM, a change in the approach to mathematics education will be needed. The focus of instructional time will have to shift from drill to problem solving. Not only word problems, but also process problems should be included in the curriculum. (Osborne, 1982; Lester, 1982) Classroom environments should foster creativity and an inquiring attitude so that children will feel free to use trial and error, estimation, and guess and check strategies. There may be several ways to solve a problem or several solutions to one problem. (Meiring, 1980) Changes in training of prospective teachers and inservice for current teachers will be needed. Textbook publishers will have to include process problem solving in math texts. Materials for teachers to use should be made available. Evaluation procedures, including standardized tests, must assess problem solving skills.

STATEMENT OF THE PROBLEM

In its An Agenda for Action, the National Council of Teachers of Mathematics recommended that problem solving should be the major focus of school mathematics programs in the decade of the 1980s. Implementation of this recommendation required a reorganization of the mathematics curriculum, with increased

attention to the application of math to real-world problems. New materials had to be developed and research done so that effective methods of developing good problem solvers could be introduced into the curriculum at all levels.

PURPOSE OF THE STUDY

The purpose of the study was to examine the research to find out if the call by the NCTM for mathematics education to focus on problem solving in the 1980s was being implemented or had caused any changes in the approach to teaching of mathematics in the school curriculum, and to determine what materials were available for teachers who wanted to incorporate problem solving instruction into the classroom mathematics program.

ORGANIZATION OF THE STUDY

Though the annotations were placed under one of three headings, there was a great deal of overlap, with many of the readings covering two or even all three of the topics. Most of the researchers offered some suggestions for the future based on their findings. A few provided program outlines and a collection of problems for use in improving problem solving abilities.

The first part of the study included definitions of what mathematical problem solving is and why it should be the focus of school mathematics programs. The middle section focused on test results and research findings in an attempt to deter-

mine: 1) if there had been any changes in mathematics programs in response to the NCTM's recommendation, and 2) whether research had provided any clues about how to most effectively develop problem solvers. Based on information gained from research studies, proposals for the future implementation of problem-solving-centered mathematics programs were formulated. These were presented in the third section.

Annotations were arranged for the most part in alphabetical order by author under each of the subject areas.

LIMITATIONS OF THE STUDY

The National Council of Teachers of Mathematics issued its challenge to make problem solving the focus of school mathematics programs in 1980. The intention of the study was to review the research to determine what effect, if any, the NCTM's recommendation has had since then. Therefore the study was limited to research and papers published since 1980. There is a large amount of literature on the subject of problem solving published before 1980 which was omitted because it was outside the intent of the paper.

GLOSSARY

ability, problem solving: (math) -- "1) the degree of capability necessary to find the correct solution to problem situations: 2) an estimate of such ability by administering standardized tests." (Good, 2)

algorithm -- "1) in elementary mathematics, a specific, often standard, procedure for carrying out a particular computation such as the long division process or the procedure for extracting square root, 2) for the computer, a sequence of well-defined steps leading to the solution of a problem; 3) in general, a particular procedure specifying a sequence of operations for solving a problem of a given type." (Good, 25)

application -- "1) the use in particular and concrete situations of abstractions in the form of general ideas, rules of procedure, or generalized method, or of technical principles, ideas and theories which must be remembered and applied; 2) outcomes of learning and instruction involving the use of skills, knowledge, concepts, and understandings in practical situations." (Good, 35)

behavior, problem solving -- "the process of selecting from a number of alternatives those that lead to a desired goal." (Good, 60)

cognitive working system -- "a hypothetical construct describing or referring to a dynamic set of subabilities mobilized for the purpose of solving a particular problem." (Good, 113)

computation -- "a term applied to a large number of activities of varying complexity whose common characteristic is the manipulation of symbols, for example, computing sums and products of natural numbers, integers or polynomials or computing a logarithm; may or may not be accompanied by reflective thinking." (Good, 123)

concept, mathematical -- "1) in reference to form, an idea or set of ideas used to classify a set of understandings and almost always specified by a word, phrase, or symbol which names the concept; the cognitive process by which this work is associated with the set is called learning the concept; 2) in reference to content, a term used by different writers to mean anything in or related to mathematics which is not considered a skill." (Good, 125)

exercise (math) -- "that which provides opportunity for practice in the application of principles and the building of skills." (Good, 224)

heuristic -- "having to do with the act of discovery; in learning and problem solving, pertaining to those methods by which one finds and applies strategies that may transfer across tasks." (Good, 280)

learning, heuristic -- "a method of learning in which the student has the basic responsibility for solving problems that confront him." (Good, 333)

mathematics education -- "a new discipline or specialization which has emerged from mathematics and education; interest of educators in this field is typically focused on research, theory, and development of mathematics teacher-training programs, mathematics curricula, and mathematics instruction; sometimes referred to as mathematics education." (Good, 353)

problem -- "1) any significant, perplexing, and challenging situation, real or artificial, the solution of which requires reflective thinking; 2) a perplexing situation after it has been translated into a question or a series of questions that help to determine the direction of subsequent inquiry (Dewey); 3) (math) a question whose answer requires reasoning from given elements to unknown according to some set of definitions, axioms or rules." (Good, 438-39)

problem method -- "1) the method of instruction by which learning is stimulated by the creation of challenging situations that demand solutions; syn. heuristic method, 2) a specific procedure by which a major problem is solved through the combined solutions of a number of smaller related problems." (Good, 439)

problem solving -- "a process employed by all people at all levels of maturity of discovering or educing new relationships among things observed or sensed; the process includes conscious or subconscious assumption, or hypothesis, of a possible relationship within a

simple or complex system of thought or understanding, and means to test through experience the acceptibility of the assumption, the process is equivalent to research when there is refinement of the system and of process in stating and investigating the hypothesis; the solution of a problem by an individual implies discovery of a relationship that is accepted as adequate by the individual; the further testing of a solution is through search for agreement with further experience and with the discoveries of other investigators." (Good, 439)

problem solving method -- "a manner of dealing with that which is problematic; a method involving clear definition of a problem confronted, formation of a hypothetical solution (hunch or suggestion), deliberate test of a hypothesis until evidence warrants its acceptance." (Good, 439)

problem (written) -- "(word problem) a problem so stated in words (rather than in symbols) that the operation necessary for solving the problem must be determined." (Good, 439)

process problems -- "problems whose solutions require the use of thinking processes (for example, planning, guessing, estimating, forming conjectures, looking for patterns)." (Charles and Lester, 8)

skill, mathematical -- "ability to use the operational techniques of mathematics; for example, computation, induction, deduction and abstraction." (Good, 537)

ANNOTATIONS

WHAT IS MATHEMATICAL PROBLEM SOLVING? WHY SHOULD IT BE THE FOCUS OF THE MATHEMATICS PROGRAM?

National Council of Teachers of Mathematics, Inc., An Agenda for Action Recommendations for School Mathematics of the 1980s, Reston, 1980, 21 pp.

In An Agenda for Action the National Council of Teachers of Mathematics (NCTM) made 8 recommendations about the direction of mathematics education for the coming decade. The first recommendation was that "Problem solving must be the focus of school mathematics in the 1980s." It was stressed that problem solving, applying mathematics to real situations, must replace the emphasis on computational ability. The Agenda proposed that students be taught strategies to use in approaching real problems, that classroom environments foster a creative and inquiring attitude, that curricular materials be developed so that all grade levels will learn to apply mathematics to daily life situations, and that research should investigate ways to best develop problem solving skills. The emphasis on problem solving was reflected in the other recommendations also. It was urged that basic skills be expanded to include understanding and application. The amount of time alloted for mathematics instruction should be increased, and the emphasis during instructional time be shifted to meaningful problem solving. The Agenda suggested that new methods of evaluation be developed to assess problem solving abilities and training of future teachers as well as inservice for current teachers should include problem solving techniques.

National Council of Teachers of Mathematics, Inc., Priorities in School Mathematics, Executive Summary of the PRISM Project, Reston, 1981, 33 pp.

This booklet reported on a survey funded by the National Science Foundation and conducted by the National Council of Teachers of Mathematics. The purpose of the Priorities in School Mathematics Project (PRISM) was to collect data about preferences and priorities in mathematics education from a wide cross-section of samples. Included in the study were subscribers to the Arithmetic Teacher and the Mathematics Teacher, college mathematics teachers, math supervisors, principals, school board presidents and parent-teacher association presidents. The highest priority from all of the respondents was given to increased emphasis on problem solving in the 1980s. Top priority was also given to spending money for development of new materials in this area. If 15 minutes per day of additional instructional time could be given to math, all groups gave first or second priority to using the time on problem solving. A majority stated that they ranked problem solving highest because they considered it to be a crucial skill. The PRISM results showed a strong support for increased attention to problem solving in school mathematics.

Castaneda, Alberta M. and others, "Young Children and Mathematical Problem Solving," School Science and Mathematics 82:22-28, January, 1982.

The authors stated that problem solving skill is essential for survival and a most important aspect of mathematics. A problem must have several characteristics--an individual must understand the situation, see that an action is needed, decide to take action, and be unable to find an obvious solution. Therefore what is a problem for one person may not be so for another. Young children form an understanding of mathematical concepts through problem solving experiences and the use of manipulatives. The action taken to solve a problem may be: a single simple act, a series of acts, an accumulation of the results of a series of actions, or finding a pattern and predicting. Children may solve problems by acting on the actual object or using some manipulative to represent the object, by using dots or pictures in place of concrete objects, or by numerical symbols. The authors provided 20 problem solving activities which, by adaptation and variation, would be suitable for use at each level of development. Guidelines were given to help in the selection of creative problem solving activities. The authors concluded that with the use of manipulatives, children can solve complex problems and by doing so develop both mathematical concepts and problem solving skills.

Charles, Randall and Lester, Frank, Teaching Problem Solving: What, Why, and How, Dale Seymour Publications, Palo Alto, 1982, 66 pp.

The authors organized this booklet into two parts. Part I dealt with the nature of problem solving, answering the questions of what mathematical problem solving involves and why it is important. A problem was defined as having three components: 1) There is a need to find a solution, 2) No immediate answer is obvious, and 3) An effort is made to find the solution. Six different types of problems were presented, with examples of each type given. A discussion of the seven factors which may cause a problem to be difficult was given. Three types of problem solving experiences needed by students were described. These included readiness activities, general and helping strategies, and discussion of attempts and solutions. Part II presented a problem solving program which could be implemented by any teacher or school. The ideas were used successfully in classrooms by the authors. Goals, methods of evaluating student progress, and suggested time guidelines were given. An instructional model based on Polya's (1957) work was presented. It included: understand the problem, devise a plan, carry out the plan, look back. Finally, the authors demonstrated a number of ways to vary any given problem.

Lester, Frank K. Jr., "Issues in Teaching Mathematical Problem Solving in the Elementary Grades," School Science and Mathematics 82:93-98, February, 1982.

Lester began with his definition of problem solving: the process of applying known information to resolve a situation for which the answer is not known. He emphasized the importance of problem solving skills in modern society and urged teachers to take action now rather than waiting for research to answer all questions. Problems of both the textbook type and "process" kind (which require thought processes beyond simply applying an algorithm) should be used in a variety of whole class, small group, and individual work situations. Evidence of use of problem solving tools on written work should be used in evaluation of growth in problem solving ability.

WHAT DOES RESEARCH AND TESTING INDICATE ABOUT PROBLEM SOLVING IN MATHEMATICS EDUCATION?

Testing

Carpenter, Thomas P., and others, "Solving Verbal Problems: Results and Implications from National Assessment," Arithmetic Teacher 26:8-12, September, 1980.

The authors analyzed the results of the NAEP mathematics assessment test relative to performance on the problem solving parts of the test. They found that a high percentage of students were successful in solving simple one-step problems, which required only that the appropriate operation be chosen and the computation done correctly. However, problems that were non-routine or multi-step presented a great deal of difficulty. The authors recommended that less emphasis be placed on simplistic one-step problems in the instructional program. Over-reliance on this type of problem may teach students that it is not necessary to think or to analyze problems. Students should be presented with problems that contain extraneous or insufficient information. Besides learning to analyze problems, students must also be taught to check their answers for reasonableness. Not only multi-step and non-routine problems but also real problems were recommended. As long as computational skills are stressed over real problem solving skills, the authors predicted that students will continue to be poor problem solvers.

Carpenter, Thomas P., and others, "Achievement in Mathematics: Results from the National Assessment," Elementary School Journal 84:485-495, May, 1984.

The authors analyzed the National Assessment of Educational Progress testing in mathematics. They made several conclusions based on the test results. They stated that our present school curriculum over-stressed the computational proficiency of students while failing to develop estimation skills or the ability to recognize reasonableness of answers. Instructional time was spent on drill rather than on teaching understanding, resulting in a lack of understanding of the concepts behind skills. Pupils were therefore unable to apply these skills to solve a problem. Most students had trouble with any problems which required analysis and lacked the most basic of problem solving skills. Test performance indicated that pupils could not identify the unknown or see the relationships between the problem, the data, the unknown and the answer. The authors urged that priority be given to fundamental concepts and application of mathematics to non-routine problem solving.

Lindquist, Mary Montgomery, and others, "The Third National Mathematics Assessment: Results and Implications for Elementary and Middle Schools," Arithmetic Teacher 31:14-19, December, 1983.

The authors presented a study of results from the third mathematics assessment, which was completed in 1982. Calls for placing more emphasis on problem solving were made in 1980. The assessment indicated that there had been very little progress or improvement in problem solving ability in the two years since the previous assessment. Students were successful in solving simple one-step problems but still had trouble with multi-step or non-routine problems. Schools still failed to develop the higher level cognitive skills and continued to place too much emphasis on lower level skills and minimum competencies. The authors stated that three changes are needed: the emphasis must shift from stress on memorization to application of mathematics to real problems, textbooks must strive for higher level cognitive skills rather than routine knowledge, and teaching techniques must include discussion of a variety of solutions to problems instead of stressing one correct answer.

Bidwell, James K., "Calculation Skills vs. Problem Solving, Scotland vs. Michigan, School Science and Mathematics 83:682-693, December, 1983.

Bidwell reported on a study he conducted in which sixth grade children in Scotland and in Michigan were given a test designed to measure calculation skills and understanding, or problem solving, skills. He compared scores on the two types of questions and concluded that the students performed much better on rote calculation problems than on even the most simple understanding questions. Children seemed conditioned to attempt calculation even when thought and logic would produce a correct solution to a problem. Also lacking was an ability to grasp what a problem was asking. Children in Scotland were more willing to try all of the problems, leaving fewer unanswered questions. Bidwell stated that schools do not seem to be producing good problem solvers. He recommended that emphasis be shifted from training students who are able to do rote calculation to teaching students to apply mathematical knowledge, and to know when and how to use a calculator to solve problems.

Research Findings

Carpenter, Thomas P., and others, "Problem Structure and First-Grade Children's Initial Solution Processes for Simple Addition and Subtraction Problems," Journal for Research in Mathematics Education 12:27-39, January, 1981.

This study was conducted with first grade children to determine how well they could solve verbal addition and subtraction problems before the algorithms were taught in school, and also to observe what strategies were used to solve these problems. A set of 10 verbal problems was designed with three being addition and seven being subtraction problems. The types included joining, part-part-whole, comparison, separating, and equalizing problem types. The problems were read to the children, cubes were available for use, and the method of solution was observed by the interviewer. Strategies used were counting all, counting on, counting back, separating, matching and heuristic. The high level of success found in the study indicated that children have developed strategies to solve problems even before instruction. In fact it may be preferable to introduce verbal addition and subtraction problems before teaching the algorithms rather than the reverse which is the traditional method of instruction in math programs.

Donahue, Gabriel Mary, "Problem-Solving Strategies Used by Elementary School Children in Solving Routine and Nonroutine Word Problems in Mathematics," Dissertation Abstracts International, 43A:387-388, August, 1982.

Donahue compared the methods used by second and fourth grade children in solving both routine and non-routine problems. The second graders showed more dependence on counting and the use of a calculator, while the fourth graders preferred written or mental calculations. When solving the non-routine problems, the children used a variety of strategies. Some methods used by the children were ones not normally taught in elementary schools, indicating that children, independent of school instruction, can and do develop their own procedures to solve problems. Donahue concluded that introduction of problem solving techniques in the instructional program would be appropriate at the second grade level.

Glynn, K. Denise Muth, "Reading Comprehension Ability and the Solution of Arithmetic Word Problems," Dissertation Abstracts International 42A:3524, February, 1982.

The purpose of Glynn's study was to determine the effect of such variables as pupil's reading comprehension level and arithmetic computational ability on their problem solving success. In addition, the effect of problem content and sentence structure variables were also studied. Four versions of a test were administered. Content variations were absence or presence of extraneous information. Structure variations were simple sentences as opposed to complex conditional sentences. A high correlation was found between the reading and computational ability of the student and success in solving the problems. In addition it was found that the inclusion of extraneous information increased the level of difficulty while changes in sentence structure seemed to have little effect.

Ludlow, Barbara L., and Woodrum, Diane T., "Problem-Solving Strategies of Gifted and Average Learners on a Multiple Discrimination Task, Gifted Child Quarterly 26:99-103, Summer, 1982.

Ludlow and Woodrum designed a study to compare gifted and average learners in their use of hypothesis testing strategies in a problem solving situation. Since superior problem solving ability is considered to be a characteristic of giftedness, it was expected that gifted students would perform better than average students. This hypothesis however was not supported by the evidence; in fact, the average learners used superior strategies in some situations. A high IQ may indicate high academic achievement but not be a reliable predictor of creative thinking ability. One implication of the study is that all students, gifted as well as average, need to be taught such problem solving skills as use of effective strategies and creative thinking. Curricula stressing the higher level cognitive abilities must be developed.

Moses, Barbara, "Individual Differences in Problem Solving," Arithmetic Teacher 30:10-14, December, 1982.

According to Moses, three difficulties can interfere with success in problem solving: entry into the problem, basic skills, and general cognitive skills. Entry into the problem is concerned with motivation, relevance of the problem and student interest. Included in basic skills is the ability to read and understand the problem, as well as computation ability. General cognitive skills which are essential for problem solving include flexibility in thinking, visualization skills and the ability to form analogies. Moses suggested techniques for diagnosing the cause of pupil error or difficulty in classroom work. Research has shown that level three is the most frequent cause of problems because development of general cognitive skills is not included in most instructional programs. Moses stated that students need improved visual perception training and suggested activities with tangrams, geoboards, and Soma cubes as means of developing these visual perception skills.

Quintero, Ana H., "Conceptual Understanding in Solving Two-Step Word Problems with a Ratio," Journal for Research in Mathematics Education 14:102-112, March, 1983.

Quintero studied the causes of errors made by elementary school children when multi-step problems are being solved. She found that the difficulty can be caused either by a lack of understanding of the concepts and relationships expressed in the problem or by a failure to plan and organize a solution method. The problems used in the study contained a ratio relationship. Besides being asked to solve the ratio problem, the children were also asked to repeat the problem and choose pictoral representations which corresponded to the problem. Those who solved the problem correctly usually were also able to correctly repeat the problem and select the correct pictoral representation. The study indicated that an understanding of the concepts and relationships in a two-step word problem is essential. The concept of ratio presented difficulty for many. Also the two-step problems presented further difficulty for the children who lacked a plan or method for solving them. More study is needed so that strategies to overcome these difficulties can be designed.

Robinson, Bertha Louise, "An Investigation of the Effects of Teaching General and Specific Strategies for Word Problem Solving to Primary Grade Children," Dissertation Abstracts International 43A:711, September, 1982.

Robinson studied what effect a structured program to teach problem solving strategies to children in the primary grades would have. A pretest was administered before a program of 22 thirty minute teaching sessions was held. In the instructional program children were introduced to a basic four-step strategy as well as work with diagrams. Posttests were then administered. In each of the four measures used in the study there was an increase in the mean score. Modeling with counters, modeling with diagrams, writing number sentences, and obtaining the correct answer when modeling with counters or diagrams all showed significant (at the .001 level) increases.

Silver, Edward A., and Thompson, Alba G., "Research Perspectives on Problem Solving in Elementary School Mathematics," The Elementary School Journal 84:529-545, May, 1984.

The authors stated that despite general acceptance of the importance of problem solving, test results show that pupils are not capable of solving mathematical problems. They noted that there is a lack of agreement about the meaning of problem solving, with some referring only to routine story problems while others include non-routine problems or even logical puzzles and games. Despite this lack of concensus, the authors felt that research has provided some information of importance. This included: 1) characteristics which influence problem difficulty, such as syntax, linguistic content, structure, 2) the relationship between reading ability and ability to solve mathematical problems, 3) characteristics common to successful problem solvers including cognitive abilities such as visualization and estimation skills and affective factors, i.e., motivation, perseverance and confidence, 4) success of programs to teach pupils how to use strategies to solve problems and 5) the importance of understanding and skills in problem representation. They concluded that study of the research findings and methods could help teachers to improve the problem solving skills of the children they teach.

Spencer, Patricia J., and Lester, Frank K., "Second Graders Can Be Problem Solvers!" Arithmetic Teacher 29:15-17, September, 1981.

Spencer and Lester reported on a program which they implemented in a second grade classroom. The purpose of the program was to introduce process problems, i.e., problems which require the use of thinking strategies, into the mathematics curriculum. The problem solving instruction was intended to develop student ability to think through a problem, to interpret information, and to form a plan for solving the problem. Specific attention was given to selecting or modifying problems so that they were suitable for the second grade level. Each lesson was based on a five day schedule: day 1 - introduction of the problem and thorough discussion; days 2, 3, and 4 - processing and planning; day 5 - comparison and discussion of solutions. The results showed that children learned to take risks and to look for a variety of ways to do the problems. Children who are taught with appropriate materials and in an accepting atmosphere do develop some skills that are necessary for successful problem solving.

Suydam, Marilyn, "Untangling Clues from Research on Problem Solving," in Problem Solving in School Mathematics, pp. 34-50, edited by Stephen Krulik and Robert E. Reys, Yearbook of the National Council of Teachers of Mathematics, Reston, 1980.

Suydam reported on research findings on the topic of problem solving. Of the 90 references she cited the majority were published in the 1970s. She organized the report into three categories: clues about children as problem solvers, clues about problems, clues about problem solving strategies. Characteristics of children who were successful problem solvers were listed as well as hints for teachers to use in helping children develop as problem solvers. Research has indicated the factors which make problems more difficult. For example, problems with extraneous information or multi-step problems have been shown to increase the difficulty level. Again Suydam presented teaching clues based on the research findings. Studies have shown that students who were taught a variety of strategies to solve problems did demonstrate improved ability to succeed in problem solving. Ways to implement the research findings in the classroom were again presented. In conclusion Suydam stated that more research must be done and quoted teaching suggestions made in 1942 by Brownwell which are still appropriate in 1980.

Suydam, Marilyn N., "Update on Research on Problem Solving: Implications for Classroom Teaching," Arithmetic Teacher, 29:56-60, February, 1982.

Suydam stated that there seems to be general agreement that effective teaching of problem solving skills is necessary. Past research has supported several generalizations including: problem solving methods can and should be taught, children need to know a variety of strategies to use in approaching a problem, and flexibility, estimation and re-checking answers for reasonableness are important skills for success in problem solving. Recent research findings have indicated five conclusions. 1) Children have the ability to solve problems before they start school, 2) When strategies and heuristics are taught, children develop better problem solving skills. (Heuristics was defined as the teaching of general skills such as drawing a diagram, simplifying a problem), 3) Multi-step problems cause students to have much more difficulty than one-step problems, perhaps because there is an over-emphasis on single-step problems in the curriculum, 4) Poor reading ability has some relationship to problem solving success but often children cannot solve problems even when reading is not a factor, and 5) The use of calculators can help children develop more problem solving strategies.

Wheatley, Grayson H., "Problem-Solving Makes Math Scores Soar," Educational Leadership 41:52-3, December 1983/January 1984.

Wheatley reported that a revised mathematics program in Marion, Indiana had resulted in significant improvement in math scores on the Iowa Test of Basic Skills. The new program stressed a process-oriented curriculum. Students were instructed in the use of heuristics to solve non-routine problems. Inservice programs for teachers were held, and a pacing schedule with time alloted for work on problem solving was adhered to by all teachers. Use of manipulatives was stressed. The resulting increase in scores in all areas (math concepts, problems, and computation) demonstrated that use of a problem solving process can surpass drill as a means of improving computational skills.

Whitaker, Donald R., "Mathematical Problem Solving Performance as Related to Student and Teacher Attitudes, School Science and Mathematics 82:217-224, March 1982.

Whitaker reported on a study he undertook to investigate how the attitudes of teachers and students toward problem solving affected the performance of the pupils. He investigated the attitudes of children in the fourth grade and of teachers of fourth grade toward problem solving. He also questioned whether teacher attitude affected pupil attitude and/or performance and the reverse situation, did pupil attitude and/or performance affect teacher attitude. The students were tested to discover their competence in the areas of comprehension, application, and problem solving. Testing showed that overall the fourth grade students were not competent problem solvers when the problem was phrased in a way that the solution was not obvious. Both teachers and students showed favorable attitudes towards mathematical problem solving. It appeared that pupil performance had a greater effect on teacher attitude than teacher attitude had on pupil performance. Also it seemed that teacher attitude had more of an effect on pupil attitude than vice versa. The author concluded that teachers should foster favorable student attitudes and also must include more multi-step problems in the instructional program.

Charles, Randall I., and Lester, Frank K., "An Evaluation of a Process-Oriented Instructinal Program in Mathematical Problem Solving in Grades 5 and 7," Journal for Research in Mathematics Education 15:15-34, January, 1984.

Charles and Lester developed a Mathematical Problem Solving program based on three principles which have been proven by research: 1) to improve problem solving skills it is necessary to solve problems, 2) the ability to solve problems grows slowly and 3) students do benefit from systematic instruction in problem solving. They compared fifth and seventh grade students who were instructed in MPS to those taught from the regular textbook. Teachers used MPS to involve students daily in problem solving experiences, consisting of skill activities, process problems or translation problems (either simple or complex). The program was structured, with lesson plans provided for each day. Results showed an improvement in the treatment group in problem solving skills and teachers expressed positive attitudes towards their ability to teach problem solving. Students also gained in confidence and learned "to think". The authors recommended that more research be done to gain additional information about how effective problem solvers can be developed through school instruction.

WHAT MUST BE DONE IN THE FUTURE TO MAKE PROBLEM SOLVING THE FOCUS OF SCHOOL MATHEMATICS PROGRAMS?

Charles, Randall I., "Get the Most Out of 'Word Problems'," Arithmetic Teacher 29:39-41, November, 1981.

Charles stated that typical textbook word problems are intended to develop understanding of mathematical concepts. He suggested ways to use the textbook problems so that they will accomplish the goal for which they were intended. Textbooks generally present a set of problems which are matched to the concept which has just been taught. A situation of this type does not increase understanding of the concept as well as non-matched textbook problems, which require careful thought to determine the mathematical concept involved. Sources of problems that can be used include old textbooks and student-written problems. Charles felt that the typical word problem can be modified so that specific problem solving skills can also be developed. Among the set of skills believed to be helpful in making better problem solvers are: 1) identify extraneous data, 2) tell what data are needed to solve the problem, 3) make up a question for a problem and 4) extend a problem. It is easy to adapt problems to provide practice in these skills. Though there are other necessary problem solving experiences, typical word problems can play an important role in helping students understand concepts and develop skills.

Cheves, Deborah, and Parks, Terry, "Making Problem Solving Real," Educational Leadership 41:54-57, December 1983/January 1984.

The authors concurred with the opinion that problem solving instruction has been lacking in mathematics programs. They believed that the teacher's definition of what problem solving is influences both the activities chosen by the teacher and how the students perceive problem solving. It was recommended that problems be based on real life situations, and be interesting to students. Teachers were urged to model questioning on a higher cognitive level, causing students to collect and analyze data and to make decisions. Mathematical concepts and computational skills are to be used as tools in finding the best solutions to problems.

Gibney, Thomas C., and Meiring, Steven P., "Problem Solving: A Success Story," School Science and Mathematics 83:194-203, March, 1983.

Gibney and Meiring described a summer institute held in Ohio in 1980 which had the purpose of helping teachers to become better problem solvers themselves and, consequently, better teachers of problem solving. Teachers developed their own problem solving skills as they worked on a series of problems and became aware of the strategies they used to solve the problems. Teacher growth in these skills led to better understanding of how to teach them to students. Goals, use of available classroom time and methodologies were discussed by the teachers. The purpose of this discussion was to cause a change in teaching philosophy. Follow-up sessions in the fall showed that the implementation of problem solving techniques in the classroom had been successful. Since the institute was held in the summer, the participants had time to experience and grow in their personal problem solving skills. Methods to use in teaching problem solving to their students were developed. The authors stated that inservice training experiences such as this may be the way to make problem solving the focus of mathematics programs.

Krulik, Stephen, and Reys, Robert E., editors, Problem Solving in School Mathematics. Yearbook of the National Council of teachers of Mathematics, Reston, 1980, 241 pp.

In this volume 22 articles, all related to the topic of problem solving in school mathematics, were presented. All were intended to be of a practical nature with many suggestions for classroom teachers included. There were articles for all levels, from early childhood through high school. Many of the articles included a collection of higher level, or process, problems which could be valuable for teachers. Several articles were concerned with methods of evaluating or measuring problem solving ability. Advice was given in other articles about using, and expanding upon, textbook problems. How calculators could improve problem solving skills was also discussed. An extensive bibliography was presented, which listed many resources for additional problems as well as books and articles with teaching suggestions.

Lindquist, Mary Montgomery, "The Elementary School Mathematics Curriculum: Issues for Today," Elementary School Journal 84:595-608, May, 1984.

Lindquist stated that there is a great disparity between recommendations made by leaders in the mathematics field and the reality of classroom mathematics instruction. She pointed out that focus on problem solving was a recommendation of the NCTM that had become a popular conference topic, approaching a "band-wagon" situation. She stressed that problem solving is a complex skill, not easily implemented into the curriculum. The approach taken in presenting content must be changed so problem solving pervades all instruction. She urged that understanding of concepts should replace drill of skills. Since the "back to basics" movement, computation has become the only basic skill. She recommended that some changes be made in the mathematics curriculum. More integration of skills and topics was suggested as well as a re-ordering of the placement of topics. Textbook publishers were cited as the chief determiners of curriculum yet marketability takes precedence over suitability. Standardized tests have often failed to reflect what is included in textbooks and do not include items requiring a higher level of cognition. Teachers and administrators have been too bound by the tests and texts. Lindquist asserted that all these groups must work together to bring about the needed changes.

Meiring, Steven P., Problem Solving . . . A Basic Mathematics Goal. Becoming a Better Problem Solver, Vol. 1, Ohio Department of Education, Columbus, 1980, 61 pp.

This booklet, one of a two-part publication, was intended to be used as an inservice tool either by an individual or a group. It is based on the premise that a teacher who becomes a better problem solver will be better able to lead children to become better problem solvers as well. The book was designed for interactive use, as the reader works the problems presented. Each section introduced several strategies. They included: look for a pattern, work backwards, make a model, graph or drawing, restate the problem, solve a simpler problem, check for hidden assumptions, and change the point of view. Although a strategies approach to problem solving was presented, two other techniques, Polya's "See, plan, do, and check" model and the classificatory problem solving approach, were discussed. The strengths and limitations of each method were analyzed. By studying this book and working through the many problems presented, the user should become a better problem solver.

Meiring, Steven P., Problem Solving . . . A Basic Mathematics Goal. A Resource for Problem Solving, Vol 2, Ohio Department of Education, Columbus, 1980, 87 pp.

This booklet, the second of a two-part publication, provided a rationale and suggestions for including problem solving instruction in the curriculum. A review of research findings by Piaget, Brownell, Maier, Greeno and Wheatley was presented. A section on looking back strategies, which include generalizing, checking the solutions, finding another way to reach a solution or finding a different solution, was included. A strong commitment to include problem solving in the curriculum was urged. Teaching techniques to facilitate inclusion of problem solving in the classroom were presented. Suggestions were made both for large group and small group teaching, modeling, and peer learning. A variety of teaching modes including games, use of manipulatives, real world situations, guided discovery and personalized problems, as well as the traditional story problem and use of the textbook, were explained. Ways in which the teacher can provide an environment which encourages problem solving were given. One chapter gave suggestions specific to the development of problem solving skills in the primary grades.

Muller, Adelyn, and Kurtz, Ray, "Students Like Personalized Word Problems," Arithmetic Teacher 28:13-14, May 1981.

Muller and Kurtz reported that teachers feel that the word problems presented in textbooks are not relevant to the experiences of the children whom they are teaching. The authors pointed out that no book can provide problems that will meet the specific needs of a particular group of children. A solution to this inadequacy is to develop personalized word problems. As a preliminary activity specifications were given for computational problems to be designed by the class or by individuals. Based on their experience, the authors believed that children need to be able to formulate and construct specific computational exercises before they attempt to solve word problems. After working on the computational design activities, the children were assigned a homework project which required the writing of a word problem based on the daily experiences of a parent. Each of these personalized problems was then written on an index card with the name of the student who contributed the problem as a resource person. These cards were exchanged among students for practice in actual problem solving. Both pride of ownership and familiarity with the vocabulary served as motivating factors, resulting in very positive attitudes toward word problems. A file of relevant problems was quickly developed from once-a-week assignments.

Osborne, Alan, "Mathematical Literacy and Teacher Education," Journal of Research and Development in Education 15:19-29, November 4, 1982.

Osborne stated that the emphasis on process or problem solving and application in mathematics education requires a shift in goals and expectations for both teachers and students. He found current textbooks, as well as much of the supplementary material, to be inadequate, forcing teachers to develop their own curriculum. According to Osborne, three types of problems should be included in the mathematics program. The within-problem paradigm, that is, the traditional story problem, serves the purpose of developing memory and representational ability. The new-problem paradigm involves teaching heuristic processes, such as devising a plan, organizing data. Osborne urged that more research needs to be done specifically in the areas of artificial intelligence and modeling. The evaluation-problem paradigm incorporates value judgments and ethical decisions into the problem solving process. Mathematics programs have not included such decision-making processes in the past. Prospective teachers as well as those already in the field need help with materials to implement these processes of problem solving into the instructional program.

Reys, Barbara, Elementary School Mathematics: What Parents Should Know About Problem Solving, National Council of Teachers of Mathematics, Inc., Reston: 1982, 14 pp.

Reys defined problem solving as the process of applying what is already known to a new and unfamiliar situation. Ability to solve problems is a basic skill in daily living experience. Four characteristics of a good problem solver were listed: ability to identify important details, flexibility of thinking, perseverance, and a sense of knowing what is reasonable. Parents were urged to become involved in the mathematics education of their children. A number of activities and exercises were suggested to assist parents in providing problem solving practice for the child. Readily available resources such as the newspaper, license plates, phone numbers, a deck of cards, or coins were all shown to be tools to develop the problem solving abilities of the child. Parental interest and involvement also would do much to motivate the child.

Shufelt, Gwen and Smart, James R., editors, The Agenda in Action, Yearbook of the National Council of Teachers of Mathematics, Reston: 1983, 245 pp.

This yearbook reviewed the Agenda for Action recommendations made in 1980 by the National Council of Teachers of Mathematics and presented articles relative to each of the Recommendations. It stressed practical suggestions for implementing the Agenda in the classroom - ideas being used to improve mathematics education. The first Recommendation was that problem solving should be the focus of school mathematics in the 1980s. Seven articles were presented, ranging in emphasis from primary to high school levels. Many suggestions for implementing problem solving instruction were given as well as a large number of appropriate problems that could be used as a resource by the classroom teacher. Articles which related to the other recommendations also contained information and ideas which could be applied to problem solving. Recommendation 7 dealt with the education of prospective teachers as well as inservice instruction for present teachers. Two articles presented many methods of training current and future teachers to develop their own problem solving skills in order to more effectively teach these skills.

SUMMARY

Priorities in School Mathematics (PRISM), a survey funded by the National Council of Teachers of Mathematics, indicated a strong support from educators and parents for increased attention to problem solving in the mathematics curriculum. In their An Agenda for Action, Recommendations for the 1980s, the Council therefore urged that the focus of mathematics programs in the decade of the '80s should be problem solving, that is, applying mathematics to real situations. Understanding and application should be regarded as basic skills and emphasis should be shifted from computational skills to problem solving skills. Castaneda et al. saw ability to solve problems as essential for survival. They stated that what is a problem for one person may not be a problem for another. An understanding of mathematical concepts can grow from problem solving experiences. Charles and Lester (1982) defined a problem as having three elements: a need exists to find a solution, no immediate answer is obvious, and an effort is made to solve the problem. They pointed out that computational skills are less important in this technicologically advanced era. Students must be trained to analyze and find solutions to problems not yet discovered. Lester defined problem solving as applying known information to find a solution to a situation for which the answer is not known. He differentiated between the textbook types of problems and "process" problems which require more thought.

Evidence that schools are not training students to be problem solvers was presented by Carpenter (1980, 1984), Lindquist (1983) and others. By analyzing the National Assessment of Educational Progress test scores relative to problem solving from both 1980 and 1982, they were able to show that students demonstrated good performance on computational tasks, simple one-step problems. However students did not do well on multi-step problems or non-routine problems. Test performance indicated a lack of understanding of concepts, poor estimation skills, and inability to recognize reasonableness of answers. Overemphasis in instructional time on computation at the expense of application skills was cited as one cause of the problem. Bidwell also found students to be dependent on rote calculations and lacking in use of simple logic and thought.

A number of research studies have been conducted in the area of problem solving. Carpenter et al. (1981) found that first grade children using manipulatives were able to form strategies to solve problems before being taught addition and subtraction algorithms. Donahue noted that among the strategies used by second and fourth grade children were some not taught in the school program, also demonstrating that children are capable of developing their own methods of solving problems. Glynn who studied the effect of pupil's reading ability on problem solving found that there was a relationship between skill in reading and ability to solve problems. In addition, she found that extraneous information increased problem difficulty. Ludlow and Woodrum found that superior or gifted

children did not display better use of strategies to solve problems than average children. They urged that all children, both gifted and average, need to be trained in the use of various problem solving strategies. Moses found that lack of general cognitive skills, including flexibility in thinking, visualization skills, and ability to form analogies, was the main deterrent to successful problem solving. She stated that most school programs do not stress development of general cognitive skills. Quintero found that inability to solve multistep word problems can be caused by lack of understanding of concepts and relationships or inability to plan a method to solve the problem. Robinson found that test scores of primary grade children taught a strategy to use in solving problems improved. Silver and Thompson noted that test results still show that pupils have not developed problem solving skills despite the fact that the importance of that skill is generally accepted. They pointed out the fact that there is a lack of agreement about what kinds of problems are included in the term "problem solving." In presenting a review of research findings they indicated the factors, such as syntax and structure, which increase the difficulty of a word problem, the affective characteristics, motivation, perseverance, and confidence, which are displayed by successful problem solvers, and the success of programs designed to teach problem solving skills to children. Spencer and Lester developed a structured program to teach second graders how to solve process problems, that is, problems requiring the use of thinking strategies. They con-

cluded that children can develop the needed skills to improve as problem solvers. Suydam reviewed research about problem solving in 1980 and again in 1982. She stated that research has provided several answers about teaching children to be better problem solvers. Among these are: 1) children can learn to use various strategies and methods to solve problems, 2) characteristics of good problem solvers include ability to visualize, to estimate and to determine the reasonableness of an answer, and 3) multi-step problems are much more difficult for children to solve than one-step or routine problems. Charles and Lester (1984) developed a program (MPSP) based on research findings which indicated that it is necessary to solve problems in order to improve problem solving skills and that these skills develop slowly but can be taught in a systematic fashion. Comparison between students in a control group who were instructed using only the textbook and students who were instructed by teachers using the Mathematical Problem Solving Program indicated a growth in problem solving ability and confidence in the experimental group.

Because of the widespread acceptance of the importance of problem solving skills for the future coupled with the evidence that pupils are not now learning to be good problem solvers though research has shown this skill can be taught, mathematics educators have made suggestions about how to improve problem solving instruction. Charles (1981) suggested ways to modify typical textbook word problems in order to develop specific problem solving skills as well as understanding of

concepts. Charles and Lester (1982) detailed a problem solving program based upon Polya's (1957) instructional model. Cheves and Parks urged teachers to select activities and problems based on real life situations and to use higher cognitive level questions. Gibney and Meiring reported on a summer in-service program which involved teachers in problem solving activities, introduced a variety of strategies to use in solving problems, and provided teaching methods for classroom use. Follow-up sessions indicated that the teachers had changed in their teaching philosophy and their approach to the use of classroom time for math education, resulting in the successful implementation of problem solving techniques in their classes. In the 1980 Yearbook of the National Council of Teachers of Mathematics, Problem Solving in School Mathematics, twenty-two articles were presented, each containing a number of suggestions for including problem solving in the mathematics curriculum. Many higher level process problems were also given and a bibliography listed additional available resources. Lindquist (1984) urged that publishers of textbooks and standardized tests, as well as administrators and teachers, must begin to work together to revise the mathematics curriculum, so that understanding of concepts would take precedence over drill and computation. In a two-part publication Meiring presented a detailed program designed for use by individuals or groups to develop a better understanding of problem solving and to become more competent and confident problem solvers. Practice in the use of many strategies was provided, along with teaching techniques and

a collection of problems. Muller and Kurtz suggested that children become involved in developing personalized problems to be used for problem solving practice. Once a week assignments resulted in a file of relevant problems and highly motivated problem solvers. Osborne stated that teachers were forced to develop their own programs in problem solving because of the inadequacy of current texts and materials. He urged that three types of problems be a part of the math program: 1) the within-problem paradigm or traditional story problem, 2) the new-problem paradigm which involves teaching heuristics and 3) the evaluative-problem paradigm which includes value judgments and ethical decisions. Reys listed suggestions for parents to involve their children in a variety of problem solving activities at home. The 1982 Yearbook of the National Council of Teachers of Mathematics, The Agenda in Action, focused on a variety of suggestions for implementing the agenda in the classroom, and served as a resource for both ideas and problems.

CONCLUSIONS

The National Council of Teachers of Mathematics urged that the focus of mathematics programs in the 1980s be problem solving. Much of the published literature on this subject was written by persons active in the NCTM. The topic received much attention and interest in the past four years, approaching a "band-wagon" situation in the math education field. New math, the "band-wagon" of the 1960s, came and went. Problem solving could be perceived as a created issue, destined to have a similar demise.

Although there seemed to be widespread acceptance of the importance of teaching skills in problem solving in elementary school mathematics programs, in order to better prepare children for the future, mathematics instruction has not succeeded in meeting that goal. Test results demonstrated that only the most simple one-step word problems, requiring primarily computational skills but not understanding of concepts, were mastered by pupils. Research done in the 1980s determined the factors which impeded problem-solving success as well as the cognitive and affective characteristics of successful problem solvers. Research also indicated that children have some natural problem solving abilities, that working problems is a good way to improve problem solving skills, and that these skills have been successfully taught to teachers and pupils with the use of structured programs.

There was some disagreement about what to include in the term "problem solving." Some included only the word problems prevelant in most math textbooks. Most included the process problems for which heuristic strategies can be taught. A few included games, trick problems, and puzzlers as problems.

A teacher interested in improving instruction in problem solving in the classroom found no help in the textbook nor from other readily available materials. However, some sources of problems of the process type as well as suggestions for adapting the traditional story problem to multi-step or non-routine problems were availalbe. Teachers who included problem solving instruction in their mathematics program developed files of higher level problems from various sources. However, too few teachers had the time and/or the interest to seek out these materials. Inservice programs for teachers were successful in making the teachers better problem solvers and subsequently better teachers of problem solving.

It was stated that textbooks companies must begin to include higher level problems in the textbook, to provide plans in the teacher's guide for teachers to use in presenting the problems, and to publish supplementary problem solving materials, if there is to be improvement in the problem solving skills of students in the 1980s. It was further urged that emphasis in school mathematics curricula be shifted from drill in computational skills to understanding and application.

Problem solving involved thinking, applying known concepts to work out solutions which are not obvious, going from

a familiar situation to a new situation, using higher level cognitive skills, such as generalizing, visualizing, making estimates and checking reasonableness of answers. Students trained to meet a problem and carry through a plan to solve it will be better equipped to meet the demands of the future.

RECOMMENDATIONS

It is recommended that:

1. More emphasis in the mathematics curriculum be placed on the teaching of problem solving skills.
2. Continued research be done to learn the most effective methods to develop good problem solvers.
3. Textbooks shift emphasis from computational skills and drill to developing problem solving skills, as well as estimating and visualizing skills, ability to form analogies, and flexibility in thought.
4. Materials and programs to develop problem solving skills be available to teachers.
5. Both present and prospective teachers receive training in problem solving to improve their skills and make them better teachers of problem solving.

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BACKGROUND

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EDUCATION:

Saint Mary's College South Bend, Indiana	B.S. in Elementary Educ. (1954)
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Saint Monica's School Mishawaka, Indiana	1st grade (1954-1955)
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RATIONALE: I am involved in a job-sharing situation in which I am responsible for the religion, social studies, science and math programs in my classroom. Because of this situation, much of my study and interest has been concentrated specifically in the area of mathematics. I attempt continually to improve my mathematics instruction and to keep abreast of recent trends. The area of problem solving is of great importance for the future of mathematics education. Implementing problem solving activities on a primary level is of interest to me.